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Published in:
Durability of Building Materials and Components

Publication date:
2008

Document Version
Publisher's PDF, also known as Version of record

Citation (APA):
Steskens, P. W. M. H., Rode, C., & Janssen, H. (2008). Influences of the Indoor Environment on Heat, Air and Moisture Conditions in The Building Component: Boundary Conditions Modeling. In *Durability of Building Materials and Components: Globality and Locality in Durability* (1 ed., Vol. 3, pp. 1433-1440). Istanbul Technical University.

Influences of the Indoor Environment on Heat, Air and Moisture Conditions in The Building Component: Boundary Conditions Modeling

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ABSTRACT

Current models to predict heat, air and moisture (HAM) conditions in building components assume uniform boundary conditions, both for the temperature and relative humidity of the air in an indoor space as well as for the surface transfer coefficients. Such models cannot accurately predict the HAM conditions in the component and on the surface of the component with non-uniform air temperature or relative humidity distributions in an indoor space. Moreover, the heat and moisture surface transfer coefficients strongly depend on the local air velocity, local temperature, water-material interactions and water content at the material surface and surface texture of the material. The objective of the present paper is to analyze the influence of the non-uniform local air velocity near the surface of a building component on the HAM conditions in the component. A case study and sensitivity study have been used to investigate this influence. The research showed that the indoor environmental conditions and local airflow velocity have a relatively large influence on the predicted HAM conditions in a building component. The influence of the convective surface heat transfer coefficient on the HAM performance of the component is relatively large compared to the influence of the convective surface mass transfer coefficient. With respect to the analyzed building component, the investigations showed that assuming an average value for the surface mass transfer coefficient is acceptable, while assuming an average value is not acceptable for the convective surface heat transfer coefficient. The study showed that the influence on the surface relative humidity is limited.

KEYWORDS

HAM component modelling, Boundary conditions

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1 INTRODUCTION

The durability of building components is strongly dependent of the heat, air and moisture (HAM) conditions in the component. Current models to predict heat, air and moisture conditions in building components commonly assume uniform indoor boundary conditions, both for the temperature and relative humidity of the neighbouring interior air as well as for the interior surface heat and mass transfer coefficients. Due to local heat and moisture sources, imperfect mixing and microclimatic effects, temperature and relative humidity in the neighbouring air are seldom uniform. Similarly, the convective surface heat and moisture transfer coefficients strongly depend on the local air velocity, local temperature, water-material interactions and water content at the material surface and surface texture of the material. The HAM conditions on or in building components resulting from such non-uniform boundary conditions cannot be accurately predicted by current HAM models. This article investigates how the variability of the surface heat and mass transfer coefficients may affect the HAM performance of building components.

Currently, researchers assume average, uniform and constant values for the convective surface heat and mass transfer coefficients when performing a HAM component analysis. The convective surface transfer coefficients are obtained from fundamental theory or experimental work, in [Hens, 2007] for example, values of 3.5 W/m^2K and $3 \cdot 10^{-8}$ s/m for the interior convective heat and mass transfer coefficients respectively are recommended.

Previous research [Worch 2004] [Novoselac 2005] have shown that different relationships for the surface heat transfer coefficient for mixed convection near a building component have been reported. Similar experimental investigations of the relationship between the surface mass transfer coefficient and the local airflow velocity have been described in [Bednar & Dreyer 2003], [Mortensen *et al*. 2006] and [Iskra & Simonson 2007]. Other researchers, for example [Steeman *et al*. 2007], tried to determine the surface heat and mass transfer coefficients by using Computational Fluid Dynamics (CFD).

The literature study showed that a considerable number of relationships between the indoor environmental conditions and the surface heat transfer coefficients have been developed, all having their specific limitations and applications. When performing a HAM building component analysis, often, researchers arbitrarily use these relationships for a HAM component simulation, without considering these limitations. The use of these correlations may introduce errors in the predicted HAM conditions. The objective of the present paper is to analyze the influence of the non-uniform distribution of the transfer coefficients caused by variations in the air velocity near the surface of a building component on the HAM conditions on and in the component. A parameter study has been used to investigate this influence.

2 CASE STUDY

A building detail has been selected for the analysis. Two rooms (on top of each other) are connected by a lightweight concrete floor. Both rooms are connected to the outdoor climate by a wall, consisting of a layer of brick, interior mineral wool insulation and a gypsum board finishing layer. Air circulates in the room from the ceiling along the wall to the floor. The construction is presented in Fig. 1. Due to inertia effects, the air velocity near the corners (indicated by 1 and 2, Fig. 1) is relatively low compared to the average air velocity in the room. Lower air velocities result in relatively low convective surface heat and mass transfer coefficients near the corner compared to the surface transfer coefficients in the centre of the components.

First of all, lower and upper limits for the surface transfer coefficients have been determined based on the literature study. Second, the HAM performance of the component Fig. 1 has been investigated using several indoor environmental conditions and different values for the convective surface heat and mass transfer coefficients. The specific conditions which have been analyzed are described in Section 2.1. Section 2.2 presents the climatic conditions, which have been applied.

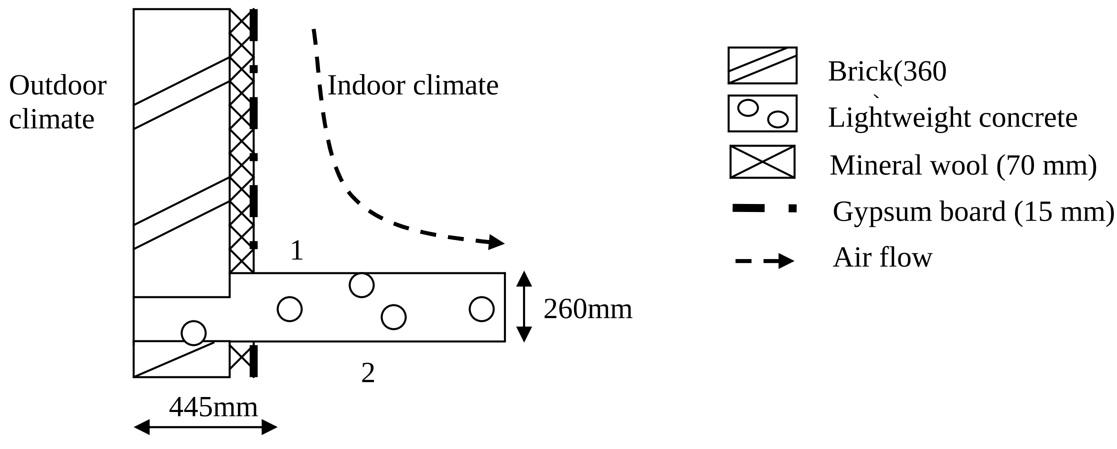

Figure 1. Building detail that has been selected for analysis. Two rooms, connected to the outdoor climate by a wall, consisting of a layer of brick, interior mineral wool insulation and a gypsum board finishing layer. Air circulates in the room from the ceiling along the wall to the floor. The surface heat and mass transfer coefficients near the corners are relatively low compared to the surface transfer coefficients in the centre of the components.

2.1 Parameter Analysis

Based on the literature study, lower and upper limits for the surface heat and mass transfer coefficients have been determined. For ‘still’ air conditions, where the local air velocity near the component is relatively low, the surface heat and mass transfer coefficient are assumed to be respectively 1 W/m^{2}K and 1·10^{-8} s/m. For ‘moving’ air conditions, where the local velocity near the component is relatively high, values of 8 W/m^{2}K and 1·10^{-7} s/m for the convective surface heat transfer coefficient ($_c$) and the convective surface mass transfer coefficient ($_c$) respectively.

Several indoor environmental conditions have been investigated:
Lower limits: A HAM component analysis assuming lower limits for the convective surface transfer coefficients has been performed.
Upper limits: A HAM component investigation applying upper limits for the convective surface transfer coefficients has been carried out.
Lower limits and average heat transfer coefficients: A HAM component analysis assuming lower limits for the surface moisture transfer coefficients and an average value for the convective surface heat transfer coefficient ($_c$) has been applied.
Upper limits and average heat transfer coefficients: An average value for the convective surface heat transfer coefficient ($_c$) has been applied, while the higher limit for the convective moisture transfer coefficient is applied.
Lower limit region: A (more realistic) situation was analyzed using a combination of a lower limit for the surface transfer coefficients in the region near the corner and upper limits outside of this layer. The size of the region has been varied between a distance of 30 cm (5a) and 10 cm (5b) from the corner of the building component

Typical values for the convective heat and moisture transfer coefficients, which have been applied for the different indoor environmental conditions, are presented in Table 1. The objective of the investigations (1 and 2) is to determine minimum and maximum HAM conditions, which are likely to occur in the building component. The objective of studying the conditions using an average value for the convective surface heat transfer coefficient (conditions 3 and 4) is to compare the influences of the convective heat transfer coefficient and the moisture transfer coefficient separately. With respect to the lower limit region, this investigation intends to determine the influence of the size of the still air region on the predicted HAM conditions.

Table 1. Convective heat and moisture transfer coefficients, which have been applied for the different indoor environmental conditions.

Conditions	$_c$ [W/m^{2}K]	$_c$ [10^{-7} s/m]
1 Lower limits	1	10
2 Upper limits	8	1
3 Lower limit $_c$ and average $_c$	3.5	10
4 Higher limit $_c$ and average $_c$	3.5	1
5a 30 cm region	1 and 8	10 and 1
5b 10 cm region	1 and 8	10 and 1

2.2 Boundary conditions

The parameter analysis has been performed using the Test Reference Year (TRY) for Danish (Copenhagen) outdoor climatic conditions. With respect to the indoor environment, hourly values for the indoor air temperature and relative humidity have been obtained using a whole building performance simulation of the building from the IEA & ECBCS programme, Annex 41, Subtask 1 [Rode & Woloszyn 2006]. The document [Rode & Woloszyn 2006] presents Common Exercise 1 which expands on Common Exercise 0 by adding an analysis of the indoor and building envelope moisture conditions for the BESTEST building used in Common Exercise 0 (from IEA SHC Task 21 & ECBCS Annex 21). The building has been simulated in HAMBASE [Wit, de 2006] using set points of 20^{o}C (during office hours) and 12^{o}C (outside office hours) for heating and 27^{o}C for cooling (during office hours). With respect to the moisture production in the building, an average vapour production of 10 litres per day is spread out over the day. The indoor environmental conditions resulting from the simulation are applied as boundary conditions on the surfaces at the internal sides.

3 RESULTS

The HAM performance of the building component (Fig. 1) has been simulated using the CHAMPS-BES Program for Coupled Heat, Air, Moisture and Pollutant Simulations in Building Envelope Systems [Nicolai & Grunewald 2006]. Outdoor and indoor climate conditions (Section 2.2) have been applied at the boundaries. With respect to the initial conditions, an initial temperature and relative humidity of 20^{o}C and 50 % RH respectively have been applied throughout the entire component. The simulation time is one year. The simulation results for 70 days are presented in Fig. 2.

Figure 2 shows that a relatively large difference is present between the lower limit (1) and the higher limit (2). Considering the average difference between both limits over the entire year, an average temperature difference of 2.5^{o}C and an average difference in relative humidity of 16.8 %RH have been observed. A difference in partial vapour pressure of approximately 77 Pa between the lower limit and higher limit condition has been observed. For temperatures around 15-20 °C and saturation pressures around 1500-2000 Pa, this is less than 4 % RH difference and may be negligible. Moreover, the partial vapour pressure resulting from both conditions (1) and (2) follow a similar trend. The influence of the convective surface heat transfer coefficient on the HAM performance is thus relatively large compared to the influence of the convective surface mass transfer coefficient. Figure 3 presents the heat and moisture fluxes to the indoor environment. Comparing conditions with lower (1) and higher limits (2), a significant difference between the size and the direction of the heat fluxes has been observed.

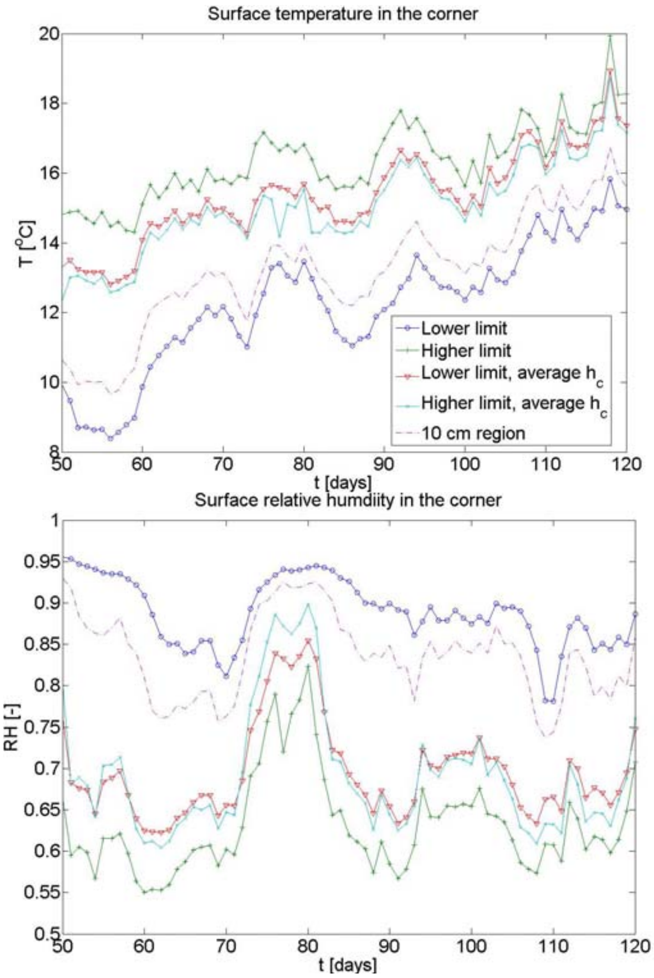

Figure 2. Surface temperature (left) and relative humidity (right) in the corner of the building component. The different conditions (Section 2.1), i.e. lower limits, higher limits and average values for the surface transfer coefficients corresponding.

Figure 2 shows that the predicted HAM conditions for the conditions with an average surface heat transfer coefficient (conditions 3 and 4) are comparable. The average temperature and relative humidity deviation over the year between conditions 3 and 4 is approximately 0.33^{o}C and 0.26 % RH respectively. The simulation results show that the influence of the surface heat transfer coefficient on the predicted HAM conditions is relatively large compared to the influence of the surface moisture transfer coefficient. In addition, the moisture fluxes (Fig.3) for both conditions (3 and 4) are relatively comparable.

Regarding the size of the still air region (condition 5), the difference in average surface temperature and relative humidity in the corner is 0.5^{o}C and 2.5 % RH respectively. Figure 2 presents relatively comparable HAM conditions even when the size of the still air region is varied by a factor 3. In summary, the investigations show that the local airflow conditions near the component (especially in the corner) should be taken into account. The size of the lower limit region, which is assumed, is less important for the conditions in the corner. However, the size of the low coefficient region will of course determine the size of the region with potential durability problems.

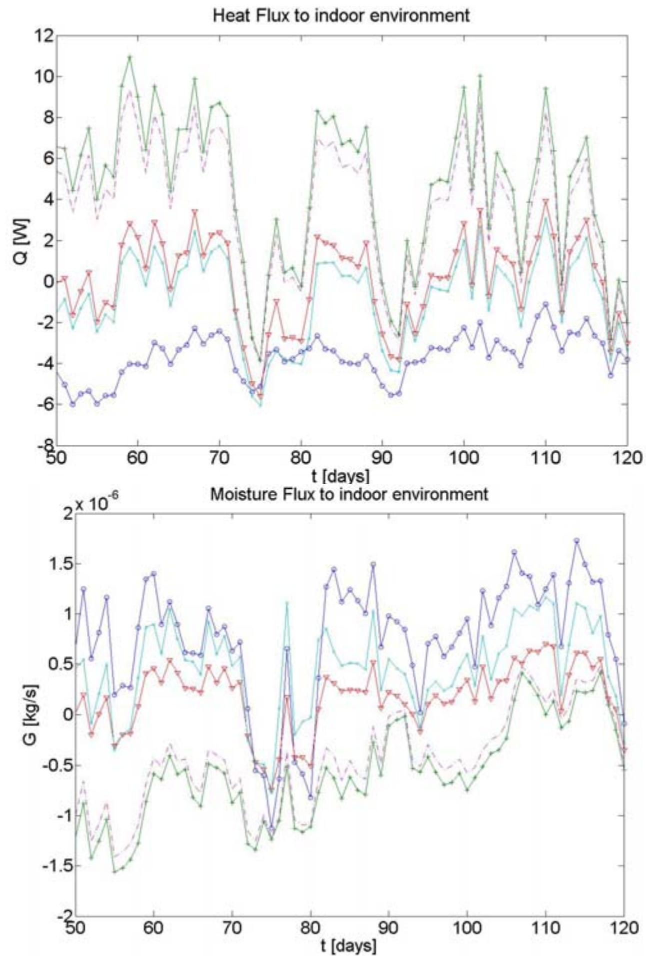

Figure 3. Heat fluxes (left) and Moisture (right) to the indoor environment. The different conditions (Section 2.1), i.e. lower limits, higher limits and average values for the surface transfer coefficients corresponding. The corresponding legend is presented in Fig. 2.

The simulation results show that a relatively large deviation is observed between the lower limit and higher limit conditions. Assuming ‘moving’ air conditions near the component, the average temperature and relative humidity in the corner are approximately 17.7^{o}C and 70 %RH. These conditions may develop moisture problems, for example mould growth. However, the risk for moisture problems is relatively small compared to the predicted lower limit conditions, i.e. an average temperature of 15.2^{o}C and a relative humidity of 87.8 %RH in the corner. Focussing on the (more realistic) case with a ‘still’ air region near the corner, these results also show that moisture problems are likely to occur. It is concluded that the application of the appropriate airflow conditions near the component has a relatively large influence on the predicted HAM performance of the component.

4 CONCLUSION and DISCUSSION

This section presents the conclusions from the parameter study and the consequences of the investigations for HAM component performance analysis. The influence of the non-uniform surface heat and mass transfer coefficients on the HAM conditions in the building component has been analyzed. A parameter study has been used to investigate this influence. Lower and upper limits for the convective surface transfer coefficients ($_c$ and $_c$), assuming respectively ‘still’ air and ‘moving’ air conditions, have been assigned. The simulated conditions resulted in minimum and maximum HAM conditions in the building component. Moreover, the combination of a ‘still’ air region near the building component has been investigated.

It is concluded that:

- The non-uniform distribution of the transfer coefficients caused by variations in the air velocity near the surface of a building component have a relatively large influence on the predicted HAM conditions in a building component. Different surface temperature, relative humidity and vapour pressures are predicted, when different airflow conditions near the component, resulting in different convective surface transfer coefficients, are applied. When performing a HAM performance analysis and simulation, it is important to take the local airflow velocity near the component into account.
- The influence of the convective surface heat transfer coefficient on the HAM performance is relatively large compared to the influence of the convective surface mass transfer coefficient. With respect to the analyzed building component, the investigations showed that assuming an average value for the surface mass transfer coefficient is acceptable, while assuming an average value is not acceptable for the convective surface heat transfer coefficient. The study showed that the influence on the surface relative humidity is limited. However, an influence on the fluxes is still present.
- Local indoor environmental conditions and deviations in local air velocities, for example due to corners, should be taken into account. A possible approach is to assume a still air region. The size of the still air region, which is assumed, showed to be less important for the quality of the predicted conditions in the corner, but will determine the possibly mould affected region's size.

Building researchers and designers should be aware that the appropriate indoor environmental conditions are applied, when performing a HAM component simulation and analysis. The local airflow conditions near the component have a relatively large influence on the predicted HAM performance of the component. It is recommended that, for example in a design stage, different local airflow conditions are investigated to predict the influence of these conditions on the HAM performance of the specific component.

Future research should focus on the analysis and determination of the relationship between the local air velocity near the component and the convective surface heat transfer coefficient. A more detailed description and prediction of the interaction between the indoor environment and the HAM conditions in the building component is desired. The quality of such an analysis could be improved by providing guidelines and relationships between the convective surface heat transfer coefficient and the local air velocity near the building component. With respect to the convective surface mass transfer coefficient, it is acceptable to assume an average coefficient.

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